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Productivity developments in European agriculture: Relations to and opportunities for biomass production

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ABSTRACT

This paper discusses if, how fast and to what maximum yield improvements can be realized in Europe in the coming decades and what the opportunities and relations are to biomass production. The starting point for the analysis is the historic context of developments in European agriculture over the past five decades. Historic developments in European crop and animal protein productivity between 1961 and 2007 show an average mean annual growth rate of 1.6%. In relative terms developments are slower on average in the Netherlands and France at 1.0% y^{-1} than in Poland and Ukraine (USSR) at 2.2% y^{-1}. In absolute figures, however, growth has been considerable in WEC and modest in the CEEC. Yield trends further show that significant yield changes can be realized over a short period of time. Positive growth rates of 3–5% y^{-1} were reached in several countries and for several crops in several decades. In Eastern European countries during their transition in the 1990s, negative growth rates as low as −7% y^{-1} occurred. Outcomes suggest that productivity levels can be actively steered rather than being just the result of autonomous developments. Current yield gaps differ greatly between Western Europe (France <10%) and Central and Eastern Europe (Poland and Ukraine 50–60%). This suggests that yields in Central and Eastern Europe, with dedicated agricultural policy, may be able to catch-up with Western European levels. Ideally, such a dedicated policy follows a leap-frog approach, meaning that past experience form the starting point for future policy development. Western European countries have developed in the direction of maximum attainable levels. This is confirmed by stabilizing yield growth rates over the last two decades. Yield improvements in this region may come from breakthrough innovations. Projections for regional growth rates differ significantly in literature resulting in different outlooks for biomass production. At the extremes the European bioenergy potential, assuming average bioenergy crop yields, can amount to 5.1–9.3 EJ y^{-1}. High yielding lignocellulosic crops could double this potential. It is concluded that the potential to free-up agricultural lands for the production of bioenergy crops in Europe is considerable. The degree to and the pace at which yields develop will determine how much of the potential is opened up. Agricultural policy and technological development are key to open up the potential.

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1. Introduction

The use of biomass resources for energy, chemicals and materials is expanding, globally and in Europe. Reasons for its use are resource diversification, emission mitigation, opportunities for rural development, *etc.* The availability of sufficient and affordable biomass feedstocks is crucial for biomass to deliver a sizeable contribution as a resource for energy and materials production. Assessments are conducted to evaluate the availability and production costs of biomass resources at current and how these can develop into the future. Developments in agricultural yields are an important factor that determines the future land requirements to satisfy food demand and thus the quantity of land that can be freed-up to be used for dedicated biomass production for energy and materials. This study will look at past agricultural productivity and examine how it may develop in the future with the aim to assess the speed at which and the extent to which biomass resources can be produced in Europe.

The potential to allocate land to bioenergy production has been assessed globally [1–4] and specifically for world regions, like Europe [5–10]. Generally, these studies consider two developments: changes in the surplus land that is available for non-food production and changes in (bioenergy) crop yields [4,11]. The combined results give the (technical) biomass production potential. Scenarios are used in order to account for uncertainties in the developments that are modeled and to make the impacts of these uncertainties on the biomass production potential explicit [12–14]. The potential studies use different assumptions and projections for future developments in crop yields and in livestock production. The possibilities to increase agricultural productivities, the rate at which this can be established therefore developed into key issues in the debate surrounding bioenergy and biomaterial options and potentials. Furthermore, it links the policy discussion on the biobased economy fully to agricultural policy and governance of land use. This is a very complex interface.

Over the past decades, agricultural production has increased in Europe as a result of area expansion and increasing productivity. For example Western European yields have roughly doubled in five decades [15]. Factors driving the demand for food and the agricultural production have been population growth and a changing diet towards a higher caloric intake. The key driving force for increasing agricultural productivities has been the intensification of agriculture, by mechanization and up-scaling, steered by dedicated agricultural policies. Ongoing production expansion in combination with a stabilizing European population [16] and caloric intakes create opportunities to allocate agricultural land to uses other than food production, one of which is bioenergy.

Given this background, the key focal points in this paper are, to assess:

(i) if yields can improve further in the next decades,
(ii) at what growth rates developments can advance and
(iii) what maximum (sustainable) yield levels can be achieved.

To make explicit what the impact of developments in agriculture is on the European bioenergy production potential the used methodology is presented together with the paper's structure. Section 3 provides an overview of driving forces that have steered agricultural developments in Europe over the last five decades. Section 4 will illustrate quantitative developments in agriculture by presenting time-series for key inputs (labour, machinery, fertilizer and pesticide) and yields (wheat, rape seed, sugar beet and cattle) between 1961 and 2007 for two Western European countries (the Netherlands and France) and two Central and Eastern European countries (Poland and Ukraine). This is followed in Section 5 by an overview of the trends in overall input application and yields for the four countries. In the same graph the key developments in policy, economy and the rural situation are presented below the quantitative trends. From this, temporal shifts within countries and differences between countries are identified and explained and future productivity development trajectories are hypothesized. Finally, in Section 6 conclusions are drawn, suggestions for further research are made and recommendations are set out.

2. Methodology

2.1. Historic developments

The analysis starts (Sections 3 and 4) with an overview of historic developments and describes the fundamental driving forces that have shaped European agriculture over the last five decades. Historic developments describe the general economic situation, technological developments, agricultural policies and structural reforms. Furthermore, the historic overview illustrates how driving forces relate to each other, for example how agricultural policy has changed as an effect of the changing economic situation and

the increasing impact of agriculture on the environment. First, the discussion is differentiated between developments in the Western European Countries (WEC) and the Central and Eastern European Countries (CEEC). The reason for this separate discussion is the distinctly different developments in these two regions at least until the 1990s due to different political systems. Secondly, more specific developments are illustrated in four countries France, Poland, the Netherlands and Ukraine. Given the distinctly different developments in the WEC compared to the CEEC, countries were considered from both regions. France is included because it is the largest producer in the WEC. Furthermore, France has historically played a key role in framing the European Union's common agricultural policy (CAP). The Netherlands has one of Europe's most efficient and technologically advanced agricultural sectors. Ukraine has been, due to its large land resources and good soil quality, one of the largest producers (and exporters) of agricultural products. Furthermore, its proximity makes it an obvious trading partner for the EU. Poland is the largest of the ten member states that joined the EU in 2004 and has a large agricultural sector. This selection does not consider any of the Mediterranean and Nordic countries.

Three dimensions were discerned that reflect the broader objectives of the agricultural policy: *supply and price stability*, *rural development* and *environmental quality*. The first two dimensions are derived directly from pillar I (direct agricultural payments) and pillar II (rural development) of EU's common agricultural policy [17]. Environmental quality has become a more explicit part of agricultural policy over the years. In the synthesis section a diagram presents the evolution of inputs and outputs and the key factors that have shaped developments in productivity under the three policy dimensions over time.

To assess developments in agricultural inputs and outputs over time, time-series are presented. Comprehensive time-series data are available, mainly from the UN Food and Agricultural Organization statistics division (FAOSTAT) [15]. Most data are recorded for the period 1961–2007. The focus of this study is on productivity developments in conventional agriculture, more specifically, on developments of land-bound agriculture. Four outputs are selected to represent improvements in productivity developments in European agriculture: wheat, rapeseed, sugar beet and cattle production. The three crops are widely produced staple crops in Europe and in the countries assessed in this study. Furthermore, each represents one of the main crop groups of starches, sugars and oil crops.

Cattle production represents developments in the production of livestock. Although livestock production itself, in the case of landless production, is not very land intensive, feed production is. The improvements in the production of livestock however focus on the efficiency to which feed is converted to meat (or dairy products. The indirect effects that (large-scale) feed imports may have on land use outside Europe are not further specified here.

The yield data give an overview of developments over time for the four countries relative to each other. The yield levels attained can also be compared to the maximum attainable yield that can be reached under local agro-ecological circumstances. The agro-ecological circumstances consider the soil and climate characteristics, usually under rain-fed conditions. The difference between the actual yield and the potential attainable yield is referred to as the yield gap. Opportunities to bridge the yield gap can come from changes in the agricultural management, land reform, *etc.*

2.2. Data input

An overview of historic yield growth rates is presented to give insight into the development speed and direction, between regions, over time and between crops. Linear regression was performed on the 1961–2007 time series. Yield growth rates are presented per country, per decade, per crop and for the entire period. Furthermore, a yield growth rate distribution histogram is presented.

As a proxy for developments in input use, time-series are presented for four key inputs: machinery, labour, synthetic fertilization and pesticide use. The time-series describe the aggregated input per country divided by the total agricultural land cultivated in a year. A more elaborate explanation of data used and the modifications made to the data are presented in a footnote to Fig. 2. The selected inputs have particularly facilitated modernization in agriculture, for example by mechanization, fertilization and weed and pest control. The selection however ignores other inputs such as water use (irrigation) and organic fertilizer (manure) application. Furthermore, it ignores production characteristics that have an effect on input use (efficiency) such as rotation schemes and farm size. The latter characteristics of agriculture are discussed in the country overview to explain developments in their broader context.

2.3. Synthesis

The synthesis section brings together the developments overview (Section 3) and the quantitative trends (Section 4) and derives and discusses cause-and-effect relations. Furthermore, the time-series data for the individual inputs and the individual outputs are combined on a country level to obtain aggregated trends for inputs and for outputs per country. For example, for all inputs (labour, machinery, fertilizer and pesticide) the trend in physical units is calculated as an index (base year 1961. From these four indexes an (un-weighted) average value is calculated for every year. The same routine is repeated for the outputs. The trends for aggregated inputs and aggregated outputs are presented in one figure. This provides a comprehensive overview of how, over time, aggregated inputs and outputs have developed, also relative to each other. Furthermore, in the same figure, below the quantitative input and output trends, the key developments in policy, economy and structural changes are presented for the three policy dimensions *price and supply stability*, *rural development* and *environmental quality*. This offers a visual overview of developments in input and output developments and the key driving forces that have steered these developments.

Next, the general trends that are observed for the WEC, the CEEC and Europe are evaluated. Historic developments are discussed in connection to the main driving forces that have facilitated growth and that have steered the direction and speed of developments. Building on these insights an outlook is sketched for how yields may develop into future. Part of this discussion is an overview of literature studies that have assessed and projected yield improvements for Europe in the coming decades. The key assumptions in the various studies, on which the projections are based, are presented and discussed. Based on both the detailed analysis of historic drivers and the literature overview, several development trajectories are illustrated for the WEC and the CEEC. These development pathways describe what preconditions in terms of policy and economic developments are required to reach certain yield growth rates over longer periods of time. Finally, the European agricultural lands that can be freed-up in the future under the different yield development projections, assumed in the different studies, are presented. Assuming average bioenergy crop yields the raw biomass potential is calculated.

3. Historic developments in European agriculture

This section provides a chronologic overview of developments in the European agricultural sector over the last five decades. Structural changes and policy developments are described for the

WEC for the CEEC and more specifically for France, Poland, the Netherlands and Ukraine.

3.1. European agricultural policy and structural changes

3.1.1. Western European countries

After the war years, European countries were determined to increase their productivity and rebuild their infrastructure. To achieve this goal countries designed national plans – like the French Monnet plan and the Dutch six year plan [18]. By the early 1950s, restoration in most countries had advanced, in isolation, to a point that allowed countries to broaden their scope with respect to strengthening their position through cooperation. A first step was the foundation of the European Coal and Steel Community in 1951 (ECSC, Treaty of Paris) which aimed to pool resources between member countries of the ECSC. Furthermore, it underlined the interdependencies between countries. The explicit framing of policy for agriculture was introduced with the foundation of the European Economic Community in 1957 (EEC, Treaty of Rome) under the CAP. The CAP recognized natural, structural and social disparities between agricultural regions and aimed to (i) increase productivity, (ii) ensure a fair living standard for the agricultural community, (iii) stabilize markets, (iv) secure supplies and (v) provide food at reasonable prices [19]. Two policy instruments were implemented to achieve these objectives: (i) intervention prices provided a (supply) price guarantee regardless of (global) market prices; similarly (ii) levies on imports and export refunds protected the internal market against low global market prices. The CAP objectives were met in the sense that agricultural production was increased and prices in the internal market were stabilized. The objectives were essentially overshot because decades later they resulted in food surpluses, adverse effects on the environment and trade distortions with the world market. As a result, opposition against the CAP increased both from within and outside the EU. Outside the EU the major opposition was directed at the distorting effects on global trade with non-subsidized producers. Within the EU criticism focused on the disproportionate benefit to larger farms while it failed to reduce the economic vulnerability of smaller farmers. Ongoing opposition led to the McSharry reform (1992) with its most important change being a shift in focus from pillar I (agricultural support) to pillar II (rural development support. The evolutionary process of decoupling eventually culminated in the 2003 CAP reform. Under the reform price guarantees were substituted by direct hectare-bound payments to farmers, the Single Farm Payments. To be eligible for support, farmers need to comply with standards concerning public, animal and plant health, environmental standards and keep their land in good agricultural and environmental condition (cross-compliance) [20]. The reform aimed to (i) control expenditures (ii) deal with support budget expansion due to the accession of ten new member states, (iii) provide a good starting point for multilateral agricultural negotiations and (iv) address consumer and agricultural issues in agricultural policy [19].

3.1.2. Central and Eastern European countries

Agricultural policy in Central and Eastern European countries has until the late 1980s been influenced by socialist governed regimes. A high priority on adequate and affordable food supply led to substantial investments in inputs for agriculture. As a result, until the 1980s, farms were collectivised and closer cooperation between agriculture, distribution and food processing was stimulated. The effect of these measures on production and productivity gains was, however, less than expected. One reason for this was the high dependency of the rural population on agriculture. In the process of centralisation of resource (e.g. fertilizer) distribution there was increasing discrimination towards private farms. Although less than expected, production increased steadily, e.g. by farm specialization, which in some countries even led to net exports of agricultural products. Subsequently, due to the desire to boost animal production, large but irregular imports of grains were required. In order to avoid over-dependence on imports, additional efficiency improvements were required. These were achieved through the establishment of large agro-complexes, which further integrated production, distribution and processing. Ongoing inefficiencies in agriculture and in the economy in general could not live up to expectations which eventually led to reforms in the late 1980s and early 1990s [21].

3.2. Country profiles: policy developments and structural changes

3.2.1. The Netherlands

Post-war rebuilding. In the post-war period efforts were directed at restoring and increasing agricultural productivity and decreasing costs and consumer prices. Over the course of five decades the role of primary agriculture (excluding secondary sectors such as manufacturing and processing) in the Dutch society and the contribution to the GDP declined gradually, from 10% in the 1950s to 2% currently. The total workforce in the agricultural sector was reduced by half. Total production in the agricultural sector (including horticulture) increased by as much as a factor of four and average food crop productivity more than doubled [22].

Intensification and up-scaling. In the beginning of the 1950s, the focus shifted to structural changes in the agricultural sector, laid down in the six-year-plan [22]. To enhance productivity several changes were deemed necessary: intensification of the agricultural practice, Growth in the size of agricultural holdings and increasing farmer specialization. The Increased size of landholdings necessitated a widespread re-allotment campaign, which proceeded well into the 1980s.

Expansion and modernization. The 1960s and 1970s were characterized by economic growth, real GDP per capita increased by 4.9% per annum in the period 1963–1973. This was accompanied by a sharp increase of capital input into the agricultural sector, facilitating rapid expansion and modernization [18]. This process was further spurred by a favourable fiscal regime which stimulated investments.

Quotas and fallow regulations. In the beginning of the 1980s this stimulating fiscal regime was largely abolished: combined with (record) high interest rates, investments stalled. Also the agricultural markets (nationally, in Europe and globally) were becoming saturated – a result of effective policy to increase productivity – which led to a change in policy. Support to farmers was reduced, production control mechanisms (e.g. quotation of grains, meat and dairy production) implemented and a fallow (set-aside) policy introduced.

Environmental legislation. The adverse effects to the environment as a result of ongoing intensification became increasingly apparent, leading, towards the end of the 1980s, to legislation that restricted organic fertilizer application [23]. Together the new policies for quotas and set-asides combined with the economic situation and new environmental legislation caused an absolute reduction of inputs (minerals, energy, pesticides and fertilizers) and led to relative efficiency improvements in agricultural production. Further regulations on fertilizer use at the end of the 1990s led to sharp decreases as well as a reduction of nitrogen in fodder and an increase in feed-conversion efficiency [24]. Although input levels were drastically reduced in absolute terms, the increase in productivity was only slowed slightly, indicating ongoing efficiency improvement. In the beginning of 2000, after two decades of steady decline, the use of pesticides increased again.

Decoupling productivity support. Moreover, for the first time in five decades, productivity levels stabilized and even decreased slightly. Several factors can be thought to be (at least partly) responsible for this; the set-aside policy which became obligatory (in 1992), stricter environmental and the decoupling of support from the productivity under the CAP.

3.2.2. France

Post-war rebuilding. The expansion of agricultural production after the Second World War has been particularly rapid in France compared to neighboring countries. This expansion is mainly due to the severe depression in the 1930s and 1940s when efficiency and innovation stalled due to low prices paid for agricultural produce and an abundance of work force. The 'First Plan' put a high priority on mechanization and fertilization. Fertilizer use quadrupled in the beginning of the 1960s compared to pre-war levels. The increased capital intensity in agriculture is clear from the expenses on input purchases which increased by 7.4% per annum in the period 1959–1973 [25].

Up-scaling and modernization. The 1960s and 1970s were aimed at increasing production by stimulating up-scaling and modernization. Much of the policy aimed at realizing structural changes was implemented on the European level, while the French domestic policy was aimed at providing social assistance to poorer farmers during the transition. In the 1960s policy initiatives lay the foundation for modernization of agriculture. Policies included the creation of pension funds stimulating early retirement, measures to encourage farmer cooperation and the creation of local government institutions that facilitated farm up-scaling. To facilitate up-scaling and rearranging of farm land dedicated rural institutions (SAFER) purchased land on the market and sold it to good qualified farmers in larger plots. The up-scaling resulted in a decrease of farm numbers from 2.3 million in 1955 to 650 000 in 2005 while increasing the average farm size from 14 to 42 ha over the same period [26]. In addition, mortality of an aging farmer population and a reduction of farms that were succeeded by farmers' children spurred the transition to farm enlargement [27]. As a result, the French rural areas depopulated, which weakened the socio-economic situation of the rural population and locally reduced the quality of the agricultural land [28].

Productivity increases and crop portfolio changes. Two developments have increased the output of the French agricultural sector: an increase in average crop productivity and a gradual shift to more productive crops, e.g. from oats to wheat and maize [27]. Combined, these developments have increased total output by 2.6% per annum between 1959 and 1974 [25].

Environmental legislation. Gradually increasing fertilization has increased pressure on the environment. Surface water contamination with agricultural nutrients in particular has raised costs for water treatment and has put stress on biodiversity. Under the CAP the cross-compliance standards amongst others regulate that in order to be eligible for support, farmers must comply with strict environmental criteria, e.g. the nitrate directive [29]. The French *national rural development plan* which started in 2000 aimed at establishing more sustainable farming systems by promoting e.g. extensive farm management, arable to pasture conversion, *etc.* A vital part of the plan was to provide financial support to farmers who switched to organic farming. As a result there was a five-fold increase of land under organic farming between 1996 and 2003 [30].

3.2.3. Poland

State control on inputs. Contrary to the large-scale collectivisation of agricultural land in most CEEC after the Second World War, more than three quarters of Polish farmland has always been privately owned [31]. State authorities, however, did not allow farmers to purchase their own agricultural machinery. Instead, state organized machinery purchases were mostly assigned to state-owned farms and to machinery stations that served cooperative farms. For this reason, animal power still dominated on 70% of private farms by 1970 [32]. In addition, the production and distribution of fertilizers was centrally planned and subsidized by the state. Consequently, state owned farms, representing less than a fifth of the farmland consumed almost a third of fertilizers [33].

Reform: economic downturn sharp decrease of inputs. Initially, the application of fertilizers dropped sharply due to fertilizer subsidy abolishment and a weak overall economic situation [33]. Reform in most CEEC was aimed at the restitution of the formerly collectivised farm land. Although in Poland the majority of land was privately owned, the country had to privatise its large state farms, making up 20% of total farm land. Under the centrally planned government, labour efficiency was low, especially in agriculture. Market liberalization during transition induced a strong reduction of demand for agricultural labour, thereby causing an outflow of labour from agriculture. This effect was most profound in regions that were dominated by state-owned farms. However, the much needed reallocation of labour between sectors, mainly from agriculture to industry and services, was severely hampered by the low level of education of agricultural workers [34]. At the same time, farmers initiated off-farm activities to improve their income levels [35].

Accession to the EU. The accession of Poland to the EU has significantly increased the total support budget for agriculture. Total expenses for agriculture support almost tripled from 1.3 billion euro in 2003 (the year before accession) to 3.7 billion euro in 2005. About half of this increase comes on the account of EU funds (CAP and structural funds) and half on increases of the Polish national budget on agriculture [36]. As a result real agricultural income per worker more than doubled (107%) between 2000 and 2009 [37].

3.2.4. Ukraine

Post-war rebuilding. Post-war Ukraine was aimed at restoration of its infrastructure and industry. Agriculture was organized in kolkhoz (cooperative farms) and sovkhoz (state farms. While state farm workers were paid a salary, cooperative farm workers were paid in money and in kind depending on the realized harvest. This system of variable payment according to harvest combined with a year of crop failure due to severe drought caused a famine in 1946–1947, immediately after which agriculture was largely collectivised [38,39].

Collective farming. In the decades that followed agriculture was characterized by centrally planned collective farming. The modest growth in agricultural productivity between 1950 and 1980 in the USSR can be ascribed to three main factors. Population growth was low and even negative in some regions; hence food demand did not increase. Labour efficiency increased, mainly due to increased mechanization. Farmers used this progress to expand the area they cultivated rather then to use their land more efficiently. Consequently, this increased the total production, but not the productivity per unit of land. Lastly, state ownership gave little incentive for farmers or managers to maximize output of the land [40].

Increased meat production. Around 1970 the Soviet Union observed the disparity between animal protein consumption between the Soviet Union and the US and Western Europe and wanted to close this gap. As a result of this, the Soviet Union placed a high priority on the increase of meat production. This policy placed a high demand on grains for animal feed up to the point where domestic production was deemed insufficient. This led to substantial, but irregular, grain imports from the world markets. The desire to keep consumer prices stable led to a situation where real yet

implicit subsidies for agriculture were increasing. This policy was very successful in raising meat consumption: by 1990 USSR meat consumption equalled that of the UK while GDP per capita was only a third of that in the UK [41,42].

Reform: liberalization and subsidy elimination. After the dissolution of the Soviet Union in 1991, Ukraine became an independent state which set into motion nationwide political, economic and institutional reforms. Agricultural production plummeted after reforms were implemented. Livestock inventories in the entire Russian Federation (including Ukraine) fell sharply [43]. Cattle herds were reduced by more than half between 1988 and 2000. The drop in domestic grain production can be largely attributed to the reduction of grain used for feed which fell 66% [44]. Key drivers of these rapid changes included trade and price liberalization and land reforms. However, the elimination of subsidies for livestock producers caused a sharp decrease in farm income. In addition, the possibility to adapt to these new and open market circumstances was hampered because institutional reforms were only implemented much later. These policy measures were anticipated to induce a short term contraction, after which market mechanisms would recover productivity, by the realignment of price levels [39].

2000s. State farms officially ceased existence by 2000. However, after a decade of reform in Russia (and other Soviet states) the forecasted increase of agricultural productivity and expansion of grain exports had yet to occur [45]. After a sharp decrease in fertilization levels during the 1990s, applications have recovered slightly, although they are still considerably lower than recommended. The modest use of inputs is not so much a matter of availability as a matter of limited financial means. For example, the high market prices paid for imported pesticides made Ukrainian farmers apply less costly and less effective domestic options. In addition, mechanical weed control is still widely used. Modern harvesting equipment is also lacking. Because of this, harvesting takes longer, a high share is lost (10–20%) and the quality of the harvest is generally poor. Despite the lack of adequate resources, production and exports have increased in recent years due to favourable weather conditions and improved crop management on larger farms facilitating record yields [46].

4. Historic quantitative trends: yields and inputs

This section presents quantitative time series that – complementary to the storylines in the previous section – explain and put into context the observed productivity and input level developments. Data are obtained from two United Nations (UN) statistics bodies, the UN Food and Agricultural Organization's (FAO) statistics division FAOSTAT [15] and the UN International Labour Organization (ILO) [47].

4.1. Crop and animal meat productivity

Depicted in Fig. 1 are the historic developments (1961–2007) for three crops and cattle production for the countries France, the

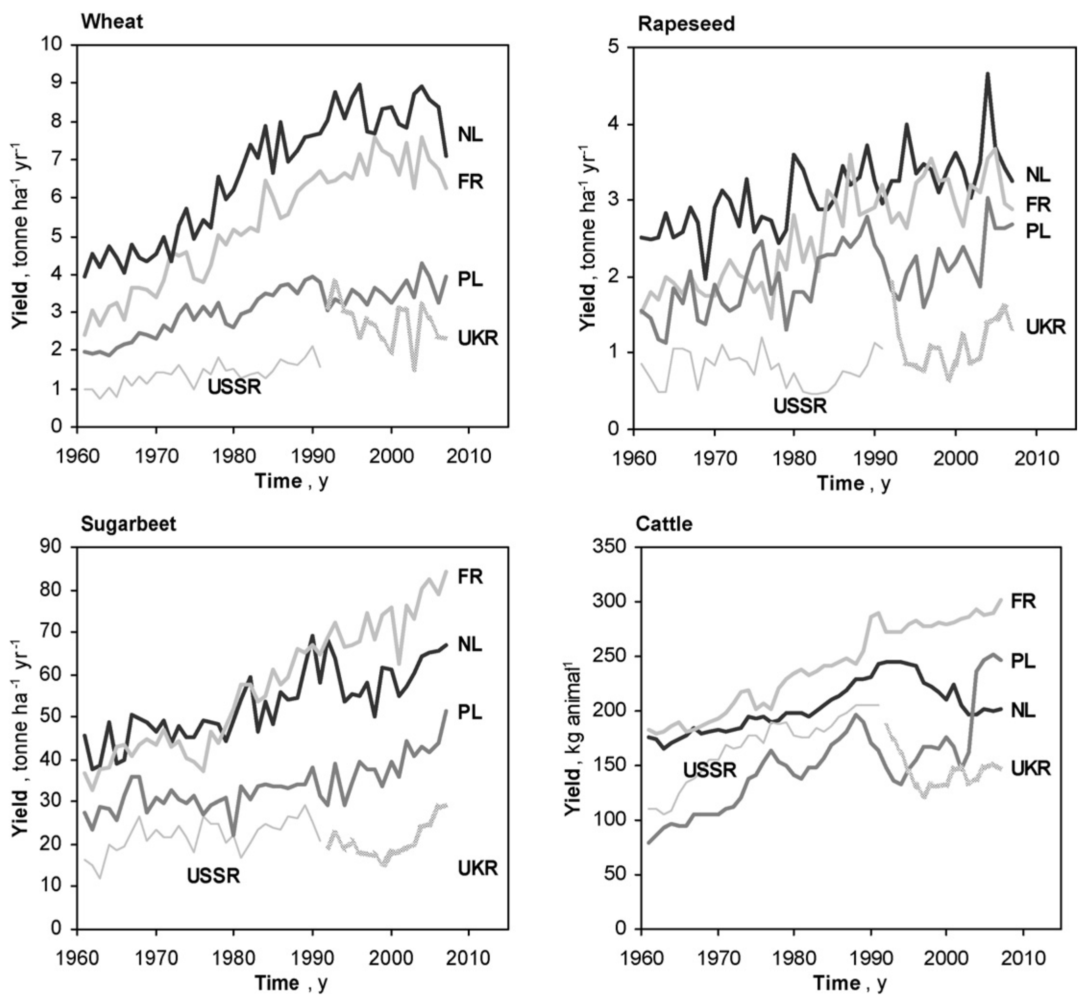

Fig. 1. Historic yield developments (1961–2007) for the crops wheat, rapeseed and sugar beet and the production of cattle for the countries France (FR), the Netherlands (NL), Poland (PL), Ukraine (UKR) and the former Soviet Union (USSR). Data derived from FAOSTAT [15].

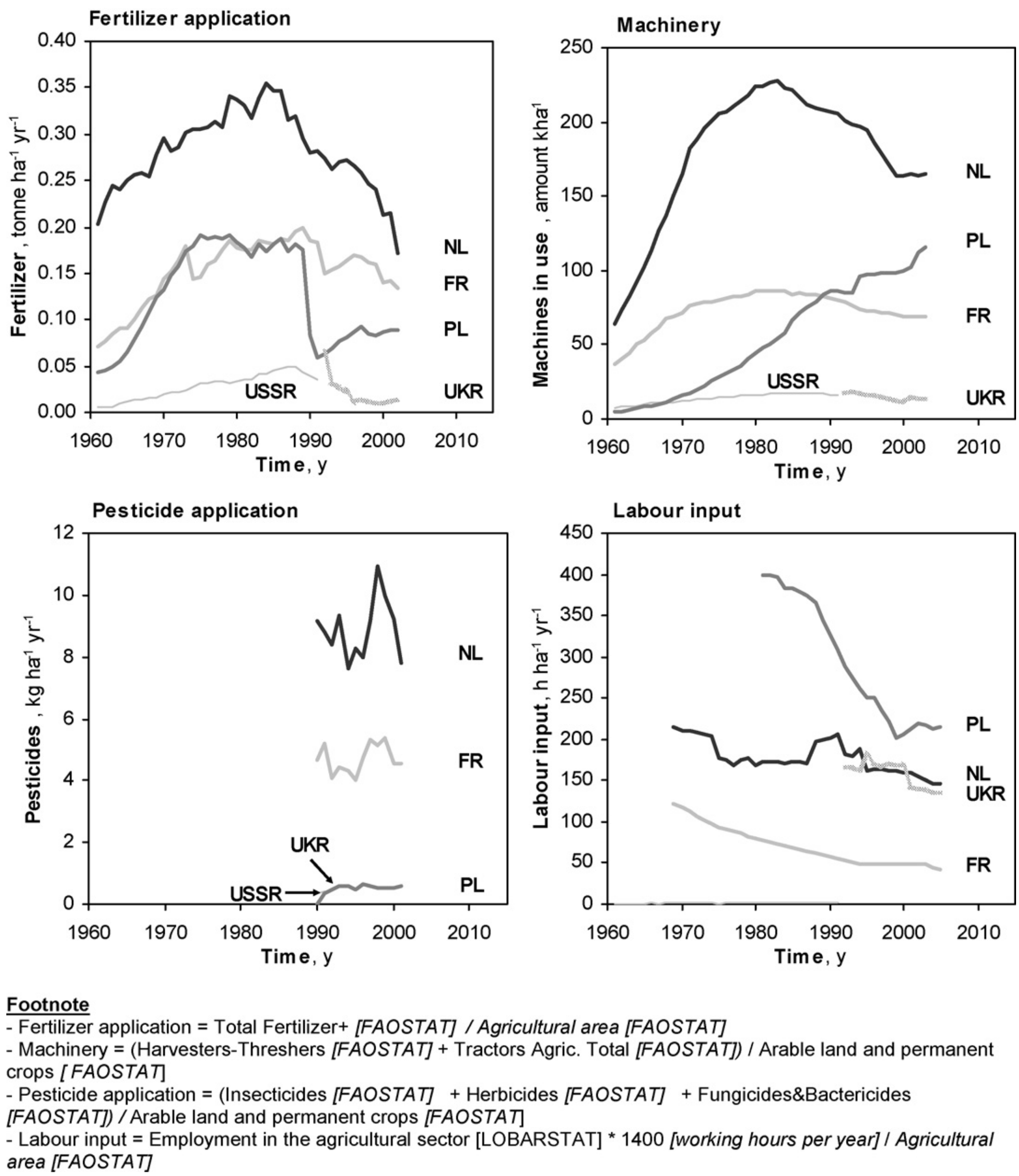

Fig. 2. Resource inputs in the agricultural sector for the resources labour, machinery, fertilizer and pesticides for the countries the Netherlands (NL), France (FR), Poland (PL) and Ukraine (UKR) and the former Soviet Union (USSR). Modified (see footnote) data, derived from FAOSTAT [15] and LABORSTAT [47].

Netherlands, Poland and Ukraine [48]. Also depicted are the developments in the former Soviet Union, since Ukraine was part of the Soviet Union prior to 1992.

Several observations follow from Fig. 1: generally, productivity developments show a continuous upward trend over 50 years (except for Ukraine). The Eastern European countries, Poland and Ukraine, had lower productivities than the Western European countries, France and the Netherlands. This is an indication that the yield gaps in Central and Eastern Europe are larger compared to Western Europe. Furthermore, at the time of the transition of the political (and financial support) system in Ukraine and Poland, Ukraine experiences clear decreases in all crops as well as cattle, whereas Poland's yields decreased less rapidly, stabilized, or even increased in the case of sugar beet.

The Netherlands shows a modest development of cattle productivity and negative growth in the 1990s and 2000s. This difference in productivity with France is explained from the large share of dairy cows that are not optimized for meat but mainly for milk production.

4.2. Inputs: resource use in the agricultural system

Agricultural production makes use of a multitude of production factors (inputs) with application levels differing per farm, region, crop, *etc.* As a proxy for development trends in input use national aggregate time-series are presented for four key inputs, machinery, labour, fertilization and pesticide use. Although this selection ignores many other inputs such as irrigation, farm size, *etc.*, it covers some important aspects – mechanization, nutrient application and weed and pest control – that have shaped agricultural development over the last decades.

Fig. 2 shows a time series overview of four resources – fertilizer, machinery, pesticides and labour – used in the agricultural sector in the countries the Netherlands, France, Poland and Ukraine. Data are obtained from the UN FAOSTAT [15] and the UN LABORSTAT database [47]. The indicators are specified per unit of land (ha) to make them comparable between countries and over time. To obtain an indicator per unit of land the aggregate consumption is divided by the amount of agricultural land that is cultivated per annum.

Labour and machinery (or capital) are substitutes for each other, although not one to one. This is roughly confirmed in Fig. 2, where labour input generally decreases and machinery use increases over time. Based on the non-linear relation between labour and machinery, at least for the Netherlands, a faster decline in labour could be expected based on the rapid increase in machinery that was put into use. This also, to a lesser extent, may apply to France and Ukraine. In these countries this effect is not clearly visible, possibly because the additional machinery put to work did not (entirely) substitute labour that was previously done by hand, but rather it led to further intensification and higher productivity per unit of land. Contrary to the latter observation, although fitting in the trend of modest productivity increases, Poland seems to comply more with the substitution relation. The (rapid) decline in labour, however, should also be viewed in the light of the large inefficiency in the workforce during the socialist era. An additional observation is the peak in machinery use in France and the Netherlands around the beginning of the 1980s. This is due to an increase in the average machine power and the emphasis on environmental regulations which focused on environmental quality rather than on output. The differences in the absolute levels of labour per hectare, for example between the Netherlands and France, may be explained by the different crop and livestock patterns in each country's agricultural sector.

Fertilization levels have increased in all countries until the end of the 1980s, after which rates declined. Declining levels have different reasons for the CEEC compared to the WEC. In Eastern Europe the decline in fertilizer application levels in the early 1990s is rapid, caused by the collapse of socialist regimes and the abrupt abolishment of agricultural subsidies. In Western Europe, the gradual decline in application levels is the result of the implemented environmental legislation such as the nitrate directive.

Pesticide application statistics are available from 1990 until 2001 and are therefore more instructive with respect to the differences in absolute application levels than that they provide information on trend developments. For example, the Netherlands on average apply almost double the pesticide amounts compared to France.

4.3. Historic yield trends

Table 1 depicts the absolute and relative productivity developments for the three crops and cattle production for the four countries assessed for the period 1961–2007 and per decade. The numbers are obtained by performing linear regression to the data presented in Fig. 1 for the periods indicated in the table.

Historic developments in European crop and animal protein productivity between 1961 and 2007 show an average mean annual growth rate of 1.6%. In relative terms developments are slower on average in the Netherlands and France at 1.0% y^{-1} than in Poland and Ukraine (USSR) at 2.2% y^{-1}. In absolute figures, however, growth has been considerable in WEC and modest in the CEEC. The volatility in average growth rates is higher in the CEEC than in the WEC.

The long term historic trends on a country level are measured by the relative growth rates for the period 1961–2007 (see Table 1). For all crops, France shows the highest long term growth rates (2.5–3.6%). In the Netherlands wheat yields have increased significantly at 2.7% y^{-1}. Although, lower when measured in relative growth rates, in absolute terms the growth in wheat yields in the Netherlands (110 kg ha^{-1} y^{-1}) barely outperforms France (104 kg ha^{-1} y^{-1}). Consequently, the difference between relative and absolute growth rates is caused by the higher absolute yield in the Netherlands in the base year (1961). Relative growth rates for sugar beet and rape seed are in the same order for the Netherlands and Poland in relative terms. Measured in absolute numbers, the average annual growth in the Netherlands is substantially higher than in Poland for both crops. Developments in cattle production show a different picture. Poland has increased productivity rapidly in the 1960s to 1980s. During the 1970s cattle productivity increased at an average of 6.1% y^{-1}. France shows a modest and stable development in cattle productivity in the period 1961–2007 (1.6% y^{-1}). Cattle productivity in the Netherlands developed modestly with an acceleration in the 1980s but negative growth in the 1990s and 2000s.

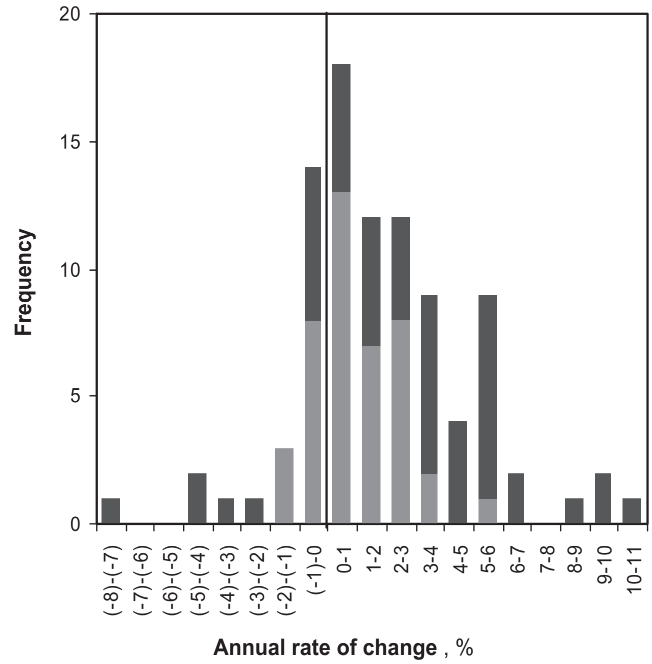

Fig. 3. Frequency histogram of the annual growth rates (analyzed per decade) observed for the three crops and cattle production for four countries between 1961 and 2007 (n = 80), specified for the WEC (light grey) and the CEEC (dark grey).

The breakdown of relative growth rates per decade allows for observation of trend discontinuities, accelerations and decelerations. After decades of growth in French wheat yields stabilization and even negative growth is visible in the period 2000–2007. A similar trend can be seen for wheat yields in the Netherlands. For other crops in the Netherlands and France no such stabilization of yield growth figures in the last two decades can be seen. The most apparent trend discontinuities are the sharp negative growth rates for all crops and cattle in Ukraine in the period 1992–1999, ranging from −3.2 (sugar beet) to −7.4% y^{-1} (rape seed). After this sharp negative growth, however, the productivity of rapeseed and sugar beet both showed sharp growth in the 2000s. A similar trend can be seen for Poland where growth stagnated and even contracted in the case of wheat and rape seed during the 1990s. However since 2000 Poland has experienced growth in yields that exceeds the country's historical averages.

Fig. 3 shows a visual representation of Table 1 in the form of a frequency distribution histogram for the growth rates per decade (n = 80). From Fig. 3 two observations stand out: growth rates in the CEEC are more volatile than in the WEC and growth rates in the range of (−1)–0% y^{-1} to 5–6% y^{-1} occur most (frequency ≥ 4).

5. Synthesis

5.1. Country developments: trends and driving forces

Fig. 4 shows the aggregated developments for productivity and inputs over time together with the main driving forces, distinguished by the three policy dimensions of *supply and price stability*,

Table 1
Absolute productivity increases and relative growth rates (italic between brackets) for the period 1961–2007 and per decade for the crops wheat, rapeseed, sugar beet and cattle production for France, the Netherlands, Poland and Ukraine.

		Absolute increase	Annual increase					
		Yield development	Entire period	Per decade				
		$kg\,ha^{-1}\,y^{-1}$ $kg\,an^{-1}\,y^{-1}$ (%)	1961–2007	1961–69	1970–79	1980–89	1990–99	2000–07
			$kg\,ha^{-1}\,y^{-2}/kg\,an^{-1}\,y^{-2}(\%\,y^{-1})$					
Wheat	France	2.4–6.3	104	136	96	125	99	−65
		(*164*)	(*3.6*)	(*5.2*)	(*2.5*)	(*2.5*)	(*1.6*)	(*−0.9*)
	Netherlands	3.8–7.1	110	31	170	95	37	−51
		(*123*)	(*2.7*)	(*0.7*)	(*3.8*)	(*1.4*)	(*0.5*)	(*−0.6*)
	Poland	2.0–3.9	39	67	59	116	−23	56
		(*83*)	(*1.8*)	(*3.6*)	(*2.3*)	(*4.1*)	(*−0.6*)	(*1.6*)
	Ukraine[a]	1.0–2.3	n.a.	44	14	47	−152	−6
		n.a.		(*5.1*)	(*1.0*)	(*3.6*)	(*−4.5*)	(*−0.2*)
Rapeseed	France	1.5–2.9	40	24	6	−8	60	36
		(*113*)	(*2.5*)	(*1.4*)	(*0.3*)	(*−0.3*)	(*2.1*)	(*1.2*)
	Netherlands	2.5–3.3	25	−16	−56	−2	20.	7
		(*46*)	(*1.0*)	(*−0.6*)	(*−1.8*)	(*−0.1*)	(*0.6*)	(*0.2*)
	Poland	1.6–2.7	21	25	8	13	12	85
		(*64*)	(*1.4*)	(*1.7*)	(*0.4*)	(*−0.4*)	(*−0.6*)	(*4.0*)
	Ukraine[a]	0.9–1.3	n.a.	24	−26	−3	−105	85
		n.a.		(*3.5*)	(*−2.7*)	(*−0.4*)	(*−7.4*)	(*9.4*)
Sugar beet	France	37–84	1024	1249	82	1267	654	1967
		(*140*)	(*3.1*)	(*3.6*)	(*0.2*)	(*2.4*)	(*1.0*)	(*2.8*)
	Netherlands	45–67	489	1041	37	704	−1204	1430
		(*54*)	(*1.2*)	(*2.6*)	(*0.1*)	(*1.4*)	(*−1.9*)	(*2.5*)
	Poland	28–51	319	910	−150	742	334	1386
		(*56*)	(*1.2*)	(*3.5*)	(*−0.5*)	(*2.6*)	(*1.0*)	(*3.7*)
	Ukraine[a]	16–29	n.a.	1258	68	970	−683	1840
		n.a.		(*9.0*)	(*0.3*)	(*5.0*)	(*−3.2*)	(*11.3*)
Cattle	France	182–301	2.8	0.8	2.4	2.0	−0.3	2.6
		(*75*)	(*1.6*)	(*0.5*)	(*1.2*)	(*0.9*)	(*−0.1*)	(*0.9*)
	Netherlands	176–202	1.1	1.3	1.7	4.0	−2.3	−2.2
		(*30*)	(*0.6*)	(*0.7*)	(*0.9*)	(*2.1*)	(*−0.9*)	(*−1.0*)
	Poland	80–246	2.5	3.0	6.5	6.6	1.0	15.2
		(*126*)	(*2.7*)	(*3.6*)	(*6.1*)	(*4.9*)	(*0.6*)	(*10.1*)
	Ukraine[a]	110–146	n.a.	6.3	3.4	3.7	−8.6	1.6
		n.a.		(*6.3*)	(*2.1*)	(*2.1*)	(*−4.9*)	(*1.2*)

n.a.: not applicable.

[a] The relative productivity increase shown for Ukraine for the decade 1990–1999 is actually the increase in the period 1992–1999. The numbers indicated for the decades ‘1961–1969’, ‘1970–1979’ and ‘1980–1989’ are based on trends for the former USSR of which Ukraine was part prior to 1992.

rural development and *environmental quality*. The productivity and input aggregates are calculated as explained in section 2 based on the data shown in Figs. 1 and 2.

5.1.1. The Netherlands

The 1960s are characterized by rapid economic growth facilitating capital investments in agriculture. Fig. 4 shows increasing aggregate inputs in this period, mainly on machinery and fertilizer. Mechanization raised machinery purchases (+220%) in the period 1961–1975. This was partly at the expense of labour which decreased slightly. Fertilization levels increased significantly over the same period. Although aggregate productivity increased over this period, it did so much more slowly than aggregate inputs. However, those large-scale investments laid the foundation for future growth. A vital incentive was the intervention price guarantee, which provided a stable investment climate and formed a stimulus for maximizing output. Similarly, a re-allotment campaign increased the average farm size which led to scale advantages, farmer professionalization, and a migration of workers from agriculture to the industry and service sectors. Towards the end of the 1970s and the beginning of the 1980s, input levels stabilized. It became apparent that the EU’s production-focused policy had been successful in providing a stable and adequate supply of food. At the same time, general concerns had risen about adverse effects of agriculture on the (local) environment, e.g. acidification and eutrophication. In the Netherlands, manure application to the fields was responsible for eutrophication, and application levels were restricted. Subsequently, the use of synthetic fertilizer peaked by the mid 1980s. Apart from a manure surplus, EU’s dairy markets were saturated which led to a quota on milk production. As a result, towards the end of the 1980s, policy objectives shifted from output-maximization to a quality-focused approach. The first step was made in the beginning of the 1990s, but the ultimate decoupling of support schemes from production were implemented in the early 2000s. This also reduced the absolute support levels which offered possibilities for farmers to diversify to off-farm activities, hence increasing economic resilience.

5.1.2. Ukraine and the USSR

Agriculture in the USSR was organized around collective farms. Apart from the rural life this affected farm management and thereby input levels. For example, since farm labour was so abundant there was little need for farm mechanization. Significant growth was seen in fertilization levels, which increased ten-fold

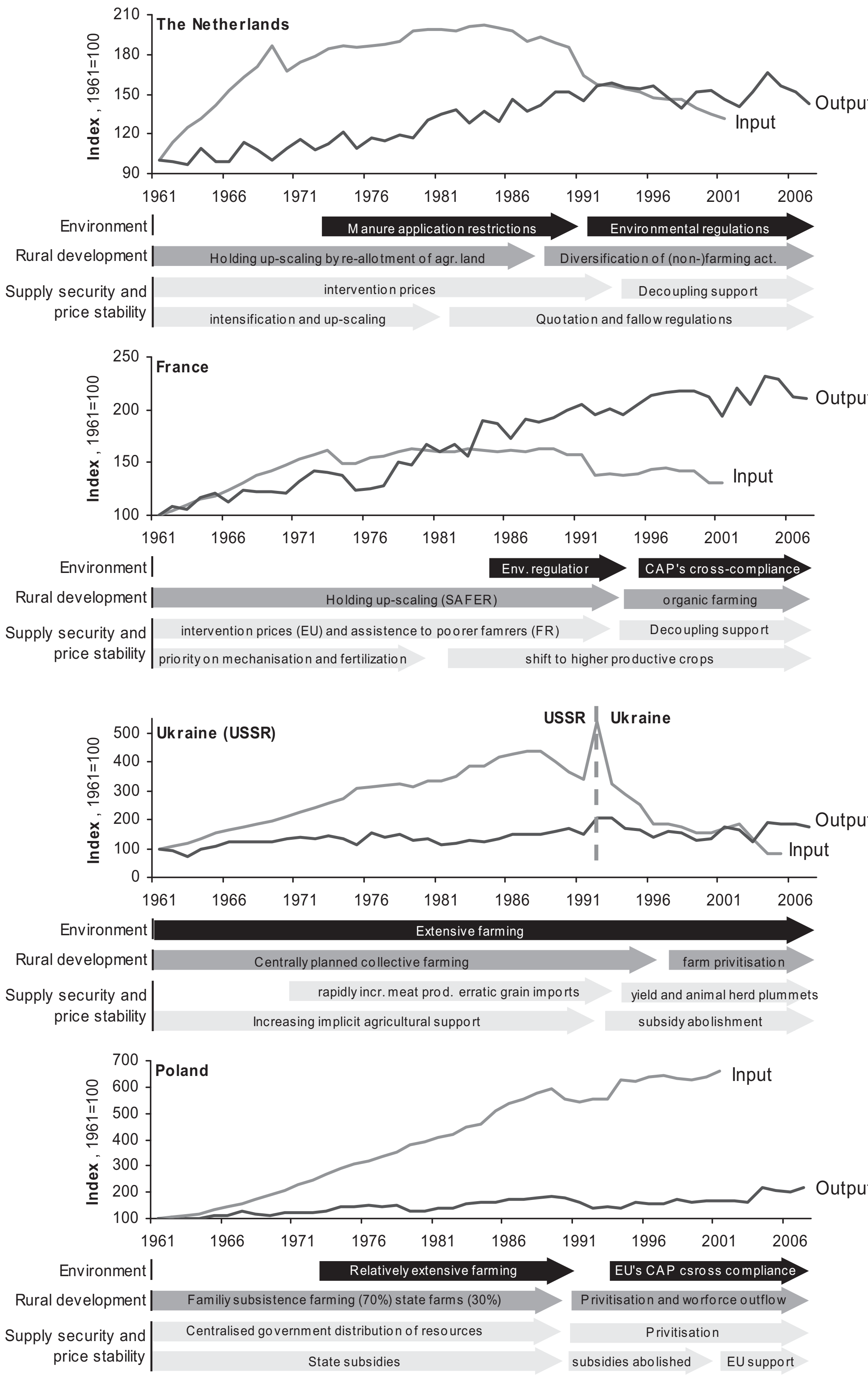

Fig. 4. Aggregated developments in productivity and resource inputs for the Netherlands, France, Poland and Ukraine and the input–output ratios (next page, Fig. 4 continued) for all countries for the period 1961–2007.

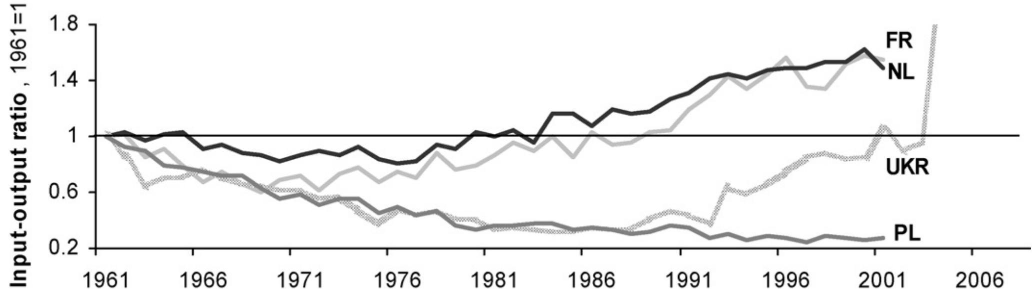

Fig. 4. (Continued).

until the mid 1980s. The five-fold increase in aggregate input levels over this period can largely be ascribed to fertilizer use and machinery purchases. This considerable relative input growth is merely caused by the low levels in the beginning of the 1960s; in the 1980s the levels cannot be considered mature yet. Growth was stimulated by state investments, implicitly subsidizing the agricultural sector, and expansion of agricultural land cultivated [49]. Fig. 4 shows a gradual but modest increase in USSR productivity levels until the late 1980s. The policy introduced in the 1970s to raise animal meat production was very successful in increasing total production and productivity levels. As a consequence, the USSR had to import large quantities to meet feed demand. The increasing aggregate inputs (technical change) did not fully materialize into augmented productivities. The main reason for this was a decline in efficiency [50]. Fig. 4 shows a peak around the 1992 dissolution of the USSR when data for Ukraine were used instead of the USSR. From this moment a sharp decline is visible in input levels and productivity. Grain production fell 31% in the period 1990–1995, after three decades of growth, due to productivity decline and a reduction of the land cultivated [49]. Reforms in the agricultural sector and economy wide were responsible for this decline. The abolishment of subsidies to agriculture sharply reduced farm income. The gradual process of privatization combined with a lack of adequate supportive policy hampered possibilities to adapt to the new circumstances. Productivity and input levels by the end of the 1990s had almost fallen back to levels of the 1960s. During the beginning of the 2000s after the fall in productivity and inputs, levels recovered somewhat, but were still below the levels of the early 1990s [51].

5.1.3. France

Agricultural productivity increased gradually in the 1960s and accelerated during the 1970s to mid 1980s. Induced by investments, input use (technical change) was stimulated. Initially input use did not fully materialize into productivity increases, explaining a decline in the input–output ratio (Fig. 4) in the 1960s. From the 1970s onwards the technical change more than offset minor efficiency losses [50], thereby increasing the input–output ratio. Contrary to crop productivity developments, increases in livestock productivity were mainly steered by efficiency improvements [52]. Whereby technical change is steered mainly by mechanization and increased fertilizer use (Fig. 2). After sharp input increases in the 1960s, input levels stabilized around the mid 1970s. Despite stabilizing input levels, productivities increased thereby increasing the input–output ratio. These further efficiency gains came from farm up-scaling, farmer professionalization and ongoing crop specialization. Average farm size increased from 14 to 42 ha between 1955 and 2005. This had a major influence on rural life which was previously small-scale and family run. As a result, there was a transformation to farmer professionalization and an outflow of workforce towards services and industry. Furthermore a shift was made towards the production of high yielding crops, e.g. from oats to grains and maize. Since the late 1980s, input levels have decreased and productivity growth has decreases. The input decrease can be ascribed to decreasing fertilizer use and a reduction of machinery purchases. Adverse environmental effects due to (over) fertilization led to implementation of stricter environmental regulations which decreased the use of fertilizers. In addition, machinery input decreased because mechanization was by that time wide spread and farm equipment increased in average power. From the 1990s and proceeding into the 2000s, the decoupling of financial production support and an increase of land under organic farming, prolonged the gradual trend of decreasing input levels. This also led to a further decrease in productivity growth. The (new) agricultural policy put more emphasis on quality standards of the land to be eligible for financial support.

5.1.4. Poland

Poland's agriculture was largely centrally planned and strongly subsidized until the late 1980s. Although subsidy allowed for rapid and considerable increases of inputs, resource distribution was uneven between state and private farms. Large-scale machinery purchases supported rapid mechanization, although this occurred mainly on state farms through the 1970s. Also fertilizer input increased rapidly. An uneven and distorted allocation of resources and a lack of economic incentive for efficient use of inputs, however, translated into modest productivity increases, reflected in a decreasing input–output ratio (Fig. 4) [53]. Despite stabilizing fertilizer levels around the mid 1970s and sharply decreasing labour inputs, aggregate inputs continued to increase mainly due to strong ongoing mechanization. Although mechanization increased the agricultural efficiency, on the input–output ratio the effect was neutralized because of poor resource distribution and modest farm up-scaling [54]. In the late 1980s, just before transition, subsidy levels peaked. The transition in the beginning of the 1990s was characterized by subsidy cuts (or abolishment) for farmers and consumers, leading to decreasing farm income and soaring consumer prices. Cutting subsidies led to a 66% decrease in fertilizer consumption in just two years (1989–1991). Fertilizer use fell to levels used in the 1960s while machinery purchases temporarily leveled off. Thus, for Poland, machinery is the most influential component of aggregate inputs because it has increased most rapidly in relative terms. As a result, the aggregated input development for Poland (Fig. 4) only shows a slight fall in the beginning of the 1990s. Induced by falling input levels [55] crop yield levels dropped, only to recover to 1980 levels by the mid 2000s. After the collapse due to subsidy abolishment in the course of the 1990s subsidies again increased substantially in order to restore farm income and consumer prices. These ad hoc subsidy schemes were later on replaced by a more comprehensive agricultural policy with an eye on Poland's accession to the EU. Upon accession farm income increased substantially because Poland came to fall under EU's CAP [53], which translated into higher productivities and a stabilizing input–output ratio.

5.2. General trends and outlook

Historic yield developments reveal a larger volatility for the CEEC than for the WEC. The 1990s collapse of yields in the CEEC, caused by the transition from centrally planned to market economies stands out in this respect. Due to the discontinuity in the productivity development over time, a continuation of the historic trend into the future would suggest modest growth, thereby potentially underestimating the future land that could be freed-up by ongoing productivity increases. A cause-and-effect relationship can be derived by an evaluation of the economic and policy driving forces (cause) and their influence on productivity developments (effect. Apart from a larger volatility, FAO figures show that yield gaps are significantly larger for the CEEC than for the WEC. For wheat yields Poland and Ukraine realize only 40–50% of their agro-ecological potential compared to more than 90% in France [56]. Preconditions to close this gap are for example, adoption of improved technologies and practices and an adequate transport infrastructure. Meeting these preconditions relies largely on economic development and supportive policies.

For the WEC similar discrepancies exist between an outlook that is based on a continuation of historic growth figures and an outlook based on the driving forces that shape agricultural productivity. Yields in the WEC have, on average, shown considerable growth for several decades. Continuation of this trend would therefore imply substantial growth for the (near) future. Inspection of the driving forces that have facilitated this growth may, however, suggest that the future growth potential is less than the realized growth in recent decades. Historic growth was established through structural reforms, modernization, economic progress and generous government support for agriculture. Together, these developments have facilitated a gradual increase of yields in the direction of maximum attainable levels. Closer scrutiny of historic trends furthermore shows a gradual decline in the annual growth, especially over the last two decades. In addition to the closing yield gap, at the beginning of the 1990s, the EU's CAP moved from an output oriented to a 'quality' focused support scheme. This also fits the ambition to steer away from the protection of the inner (European) market to open opportunities for competition with the world market. Also organic farming expanded in Western Europe over this period. An upward deviation from the historic trend may come from breakthrough innovations that have the potential to improve the production frontier (current state-of-the-art levels. Such developments may, for example, include applications of new breeds, advances in precision farming, rotation optimization and GM crops [4,56]. In addition, agriculture could expand into saline and arid areas and explore opportunities for aquaculture [57]. It can thus be expected that yields in the WEC will develop at modest growth rates in the order of the past two decades. Unless the mentioned breakthrough innovations are implemented, growth rates may raise to levels reached in the 1960s and 1970s.

The general trends for the WEC and the CEEC show that a continuation of historic yield growth rates seems unlikely for both regions for distinctly different reasons. Given its yield gap, the CEEC is assumed to be able to raise their productivity by professionalization, improved management, *etc.*, similar to developments in the WEC in the second half of the previous century. As can be learned from the WEC example, such a catch-up strategy [58] would require a dedicated (agricultural) policy, supplying financial support to facilitate investments and reforming landownership. The adverse environmental pressures that resulted from intensification (e.g. by over-fertilization) in the WEC, until the 1980s, can be prevented by implementation of environmental legislation. Thus a leap-frog approach [59] should be followed, copying those elements that have worked well in WEC.

5.3. Projected yield trends in literature

This section provides an overview of studies that have projected future growth rates (see Fig. 5) for crop yields in Europe with the aim to assess the future land availability for bioenergy production.

The REFUEL study [13] has projected yield developments for three groups of European countries; the WEC, the CEEC and Ukraine (nonEU). Projections were constructed for three scenarios. A base scenario assumes developments that are a continuation of the historic trend. The low scenario assumes an increase in organic farming in the WEC and a continuation of extensive farming in the CEEC. The high scenario assumes opportunities for the implementation of new breeds in the WEC while the CEEC is expected to intensify production towards WEC levels. Aggregate average yield growth rates are projected for the period 2000–2030 for the three regions and are calculated at respectively 6–15% (WEC), 63–77% (CEEC) and 145–166% (Ukraine).

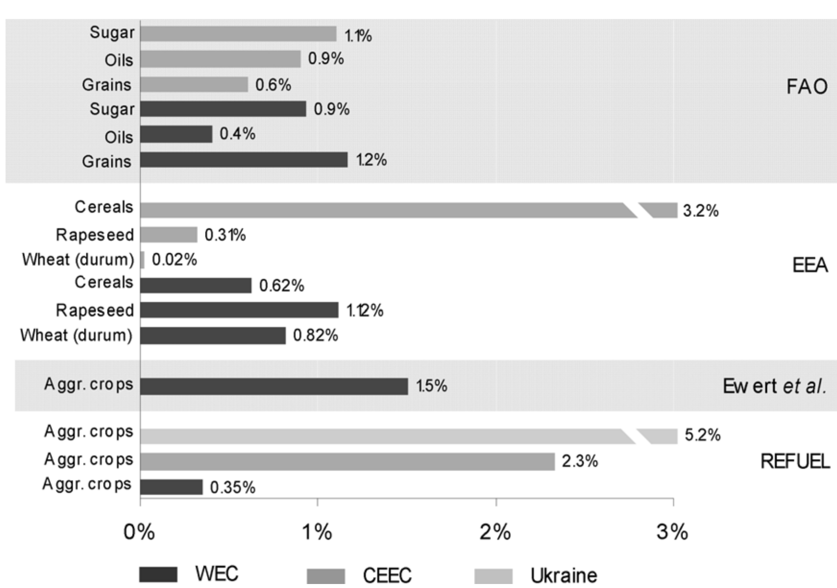

Fig. 5. Average annual yield growth rate projections for Europe for the period 2000–2030 for four studies [5,6,12,56].

Ewert et al. [12] describe yield developments for Europe considering the EU15 countries Norway and Switzerland. Linear regression was performed on historic yield data for the period 1961–2002 (obtained from FAO). Projected changes in yields were modeled taking into account effects of climate change, increasing atmospheric CO_2 concentrations, technology development and these three factors combined. In addition projections are varied for future developments reflecting the IPCC SRES scenarios, considering a future emphasis on economy versus environment and global versus regional. Hence 16 development pathways are evaluated. Results indicate possible yield increases of 25–163% between 2000 and 2080. The variation in scenario projections diverges over time. As a reference, these outcomes correspond to projected yield increase of 29–61% by 2030.

A study by the EEA [6,60] estimates the bioenergy potential for the EU22 towards 2030. The aim of the study is to assess possibilities for bioenergy production, and along these lines agricultural productivity increases, without increasing pressures on the environment. The study therefore assumes dedicating land for extensive, environmentally oriented farming, securing land for protected nature and forest areas and allocating a fraction of intensively farmed land to set-aside area to accommodate ecological development. Average WEC yields are projected [61] to change annually with 0.82, 1.12 and 0.62% y^{-1} for wheat, rapeseed and cereals respectively. For the CEEC, there is considerably larger difference between crops wheat, rapeseed and cereals are expected to increase 0.02, 0.31 and 3.2% y^{-1}.

The UN FAO [56] projects aggregate global yield developments and more detailed projections for the WEC and CEEC for the period 2001–2030 (after [62] from personal communication with Bruinsma. Projections are based on a continuation of historic trends. Estimates for yield growth are provided for several crops such as oils, sugar and grains. For the WEC, yields are projected to change with 0.40, 0.93 and 1.17% y^{-1} for oils, sugar and grains respectively. For the CEEC oils and sugar are expected to increase faster than in the WEC by 0.90 and 1.10% y^{-1} for oils and sugar and slower for grains with 0.60% y^{-1}.

Differences between yield growth projections between studies are significant. Therefore, it is interesting to compare these ranges with the historically observed growth rates (Section 4.3). Together with the insights from the synthesis in Section 5.1 some possible future pathways are examined, which place the projected growth rates into perspective by illustrating the policy measures that could be taken to reach projected yields.

Yield growth developments in the WEC at 0.5–1.5% y^{-1}, as assumed by FAO (0.8% y^{-1}), EEA (0.9% y^{-1}) and Ewert et al. (1.5% y^{-1}), are modest when compared to the historic developments between 1961 and 2007 but seem high compared to developments in the last two decades. Declining growth rates in the latter period, steered by an expansion in organic farming, set-aside obligations and a decoupling of production support, can be assumed to continue if these trends are unchanged. REFUEL projections (0.4% y^{-1}) for the WEC seem conservative in this respect.

Projected growth rates for the CEEC around 1% y^{-1} – as projected by FAO (0.9% y^{-1}) and EEA (1.2% y^{-1}) – seem modest when compared to average growth figures between 1961 and 2007, even more so when compared to growth rates prior to 1990 and past 2000. The Polish yield gap which is estimated at 45% [56] illustrates that there is ample agro-ecologic potential to improve productivities. Growth rates in the order of 2.5% y^{-1} and higher, as suggested by REFUEL (2.3% y^{-1}), have been reached during several periods for some crops in Poland. In addition, in the WEC growth rates in this range and higher have been reached, also over longer periods. Developments in the WEC in particular should be explained from the implementation of structural reforms in farm up-scaling (by re-allotment) and financial support to augment input levels. Ambitions for growth of this order for the CEEC should therefore be accompanied by stimulating policy, e.g. in the form of financial support. The EU's common agricultural policy has shifted its focus from output maximization to improvement and maintenance of the land quality and rural identity. Therefore it can be questioned whether the current CAP does provide the level of assistance to farmers to bridge the existing yield gaps.

Ukraine (and the former USSR) shows a volatile historic trend which offers a weaker basis for a future outlook. A catch-up hypothesis, similar to that for Poland (and the CEEC) could be envisioned for Ukraine. Similarities are the existing yield gap and the relatively low current input levels. The difference with the other CEEC is that Ukraine is not a member of the EU and hence does not fall under the agricultural support offered by the CAP. The REFUEL projections, originating from a catch-up assumption, for Ukraine seem very high in this respect. Although there have been periods that have shown annual increases of 5% and more, such periods are exceptions and are often reached when starting from (very) low levels and are always accompanied by stimulating agricultural policy mostly in the form of guaranteed intervention prices for farmers. Nevertheless, the potential is there.

5.4. Implications for land availability and bioenergy potentials

The growth rates projected in the studies discussed in the previous section work out differently in terms of the land that will become available for bioenergy production. Taking the agricultural land base in 2000 as a starting point the land that is freed-up until 2030 is calculated according to the growth rates presented in Fig. 6. In the year 2000 the total agricultural land in respectively the WEC, CEEC and Ukraine amounted to 143 000, 58 000 and 41 000 km^2. Assuming the total output (related to food demand) of the land remains constant, all productivity increases result in land being freed-up, potentially available for the production of bioenergy crops. Following this reasoning Fig. 6 shows the resulting land that is freed-up by 2030. All studies have considered the WEC, all but Ewert et al. have looked at the CEEC and only REFUEL considers Ukraine separately.

Fig. 6 presents the freed-up European land for four studies. At the extremes the regions WEC, CEEC and Ukraine are expected to be able to free up 14–44, 12–24 and 25 million ha by 2030 respectively. This translates in a raw biomass potential from these freed-up

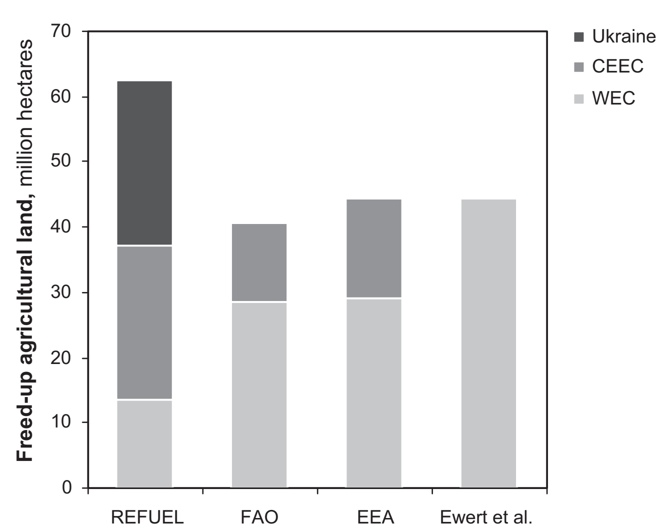

Fig. 6. Implications of land availability and bioenergy production by 2030 according to yield projections of four studies.

lands by 2030, assuming an average yield (100 GJ ha^{-1} y^{-1}), of 5.1–9.3 EJ y^{-1}. Wide-scale implementation of high yielding (herbaceous) lignocellulosic crops could double the caloric output.

6. Discussion

For the analysis, selections had to be made to the data to keep the analysis workable. One simplification is the separate discussion of two groups of European regions, the CEEC and the WEC. Discussion of these groups of countries for example allows for the discussion of the macro-developments, such as the effect of supra-national agricultural policies, on productivity developments. On the other hand, it ignores the large diversity within these groups of countries. To analyze developments in more detail, the analysis focuses on four countries, two countries per group. Another selection was made with respect to the crops and livestock considered in the analysis. Wheat, sugar beet, rapeseed and cattle production were included. Outcomes show that crops within one country generally develop in the same direction and at equivalent growth rates. A more comprehensive selection of crops and livestocks could, however, have provided more conclusive outcomes for the development of yields in the overall European agriculture. A third simplification was the focus on a limited number of inputs to represent the overall use of production factors for the production of crops and livestock. Four inputs were considered: labour, machinery, fertilizer and pesticides. This selection for example does not differentiate between skilled and un-skilled labour, for developments in the increasing power per machine over time, *etc.*

This study presents aggregate developments for inputs and outputs. Although this provides insights in the general trends, the aggregation does not uncover individual driving forces such as efficiency, technical change, allocative change, which develop at different rates and possibly in opposite directions. Only the net result of all these drivers is captured. Multi factor productivity (MFP) analysis can quantitatively decompose productivity into its individual drivers. A preliminary investigation to use this method for this study showed that such an analysis was not feasible given the large data requirements, mainly because of the length of the period studied and the number of countries assessed. Future endeavors may consider applying an MFP approach to parts of the subjects studied (e.g. sub-sectors in countries). This could provide a more comprehensive insight in the specific role that individual driving forces have had on productivity developments. Analysis – and studies discussed – in this paper assume a linear development of absolute yield figures over time. From this assumption it follows that the (annual) growth rates decrease over time. This has limitations for extrapolating fixed annual growth rates into the future, especially over longer periods of time because the relative growth rates are based on different absolute yield levels.

7. Conclusions

This paper has examined the extent to which biomass resources can be produced in Europe as a result of ongoing yield developments in agriculture. It assessed the driving forces behind, and the pace and direction of, agricultural yield developments in the past five decades in Europe. Furthermore, it explored how future yield pathways may develop under influence of economic and technological developments and policy deployment. The following conclusions are drawn:

Ongoing yield increases can open up a significant biomass potential on the short to medium term

At the extremes the regions WEC, CEEC and Ukraine are expected to be able to free up 14–44, 12–24 and 25 million hectares by 2030 respectively. Assuming an average yield of 100 GJ ha^{-1} y^{-1} on these freed-up lands, this translates in a raw biomass potential of 5.1–9.3 EJ y^{-1}. Wide-scale implementation of high yielding (herbaceous) lignocellulosic crops could double the caloric output.

European yields have increased significantly over the last five decades

Historic developments in European crop and animal protein productivity between 1961 and 2007 show an average mean annual growth rate of 1.6%. In relative terms, developments are slower on average in the Netherlands and France at 1.0% y^{-1} than in Poland and Ukraine (USSR) at 2.2% y^{-1}. In absolute figures, however, growth has been considerable in WEC and modest in the CEEC. As a consequence, the WEC has realized more of its agro-ecological potential compared to the CEEC which suggests a considerable potential for yield growth in the CEEC.

Yields are actively steered by policy: significant yield changes realized over short time periods

Results indicate a clear correlation between yield developments and the implemented agricultural policy, both in periods of positive and negative yield growth. In periods, and in countries, where stimulating policy (e.g. intervention prices) was implemented yields went up and reversely when stimulating policies were abolished yields contracted. Trend data show that significant yield changes can be realized over a short period of time. Outcomes hence suggest that productivity levels can be actively steered rather than being just the result of autonomous developments such as economic growth.

Yield growth did not always coincided with efficient use of production factors

Periods of considerable yield growth have not always coincided with periods of high (output per input) efficiencies. For example, intervention prices have facilitated investments in production factors, leading to increasing yields but sometimes to lower output-per-input efficiencies because inputs were not used efficiently in the absence of an economic incentive. To the other end, environmental legislation that was introduced in the late 1970s, mainly in the WEC, incentivized the use of (restricted) inputs efficiently. These mechanisms illustrate the importance of appropriate policy to stimulate productivity while safeguarding efficiency and (related to this) sustainability.

From these conclusions some key policy implications are derived:

Different stages of development require diverse policy needs for WEC and CEEC

Possibilities to bridge the yield gaps in the CEEC depend on the agricultural policies that need to secure farm income levels, facilitate land reforms and safeguard environmental quality. Further developments of yields in the WEC may come from (breakthrough) innovations, improved management and technical progress.

Policy development for CEEC should include lessons from developments in the WEC

Policies, particularly in the CEEC, could follow a leap-frog approach whereby past developments can give directions for developing future policies. Such policies may aim to increase agricultural output, increase yields, ensure efficiency and stimulate rural development. Policies that have stimulated agricultural output and yield increases are financial support to farmers and land ownership reform to facilitate up-scaling. Other policy instruments have stimulated (resource) efficiency such as environmental legislation restricting input application and balancing demand and supply by quota systems and set-aside policies.

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